β-decay study of ^{6}He & ^{11}Li

Jeroen Büscher Riccardo Raabe
Piet Van Duppen Mark Huyse

IKS - Nuclear Spectroscopy

IAP-day, Leuven - January 23, 2007

What are halo nuclei? - How to probe?

I.Tanihata et al.
Phys. Rev. Lett. 55, 2676 (1985).
Phys. Lett. B 160, 380 (1985).

P.G.Hansen, B.Jonson
Europhys. News 4, 409 (1987).

J.Al-Khalili, E.Roeckl (Eds.)
The Euroschool Lectures on Physics with Exotic Beams, Vol.I;II.
Springer .

- very weak binding : valence nucleons - compact core
  spatially extended wavefunctions
- few-body cluster models
- short lifetime [ms-s] ⇒ Radioactive Ion Beam Facilities
- how to probe?
  1. nuclear reactions - model needed for the reaction
  2. β-decay

What are halo nuclei? - How to probe?

I.Tanihata et al.
Phys. Rev. Lett. 55, 2676 (1985).
Phys. Lett. B 160, 380 (1985).

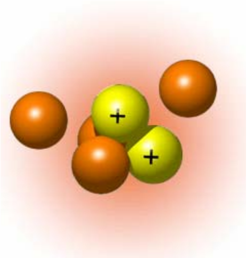
P.G.Hansen, B.Jonson
Europhys. News 4, 409 (1987).

J.Al-Khalili, E.Roeckl (Eds.)
The Euroschool Lectures on Physics with Exotic Beams, Vol.I;II.
Springer .

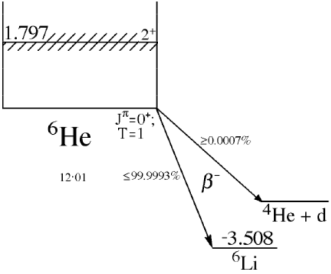
- very weak binding : valence nucleons - compact core
  spatially extended wavefunctions
- few-body cluster models
- short lifetime [ms-s] ⇒
  Radioactive Ion Beam Facilities
- how to probe?
  1. nuclear reactions - model needed for the reaction
  2. β-decay

overlap between wave functions of mother and daughter states

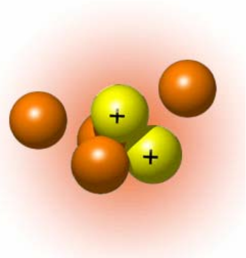
^{6}He-β-delayed charged particle emission



- α-core + two neutrons
- <1990 : 100% β-decay to g.s. ^{6}Li
  Q_{β}=3.508MeV ; $T_{1/2}$=806,7ms

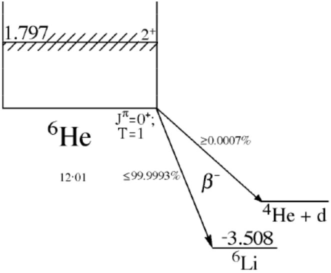


^{6}He-β-delayed charged particle emission



- α-core + two neutrons
- <1990 : 100% β-decay to g.s. ^{6}Li
  Q_β=3.508MeV ; $T_{1/2}$=806,7ms

>1990 : very small β-decay branch :
β-delayed α+d emission ; Q=2MeV



Experiment $\leftrightsquigarrow$ Theory

Experiment ⇝ Theory

K.Riisager et al.

ISOLDE (1990)

branching ratio

$[BR] = (2.8 \pm 0.5) \times 10^{-6}$

Experiment $\leftrightsquigarrow$ Theory

K.Riisager et al.
ISOLDE (1990)
branching ratio
$[BR] = (2.8 \pm 0.5) \times 10^{-6}$

P Descouvemont et al.
potential model (1992)
$[BR] = 2.0 \times 10^{-4}$

Experiment ⇝ Theory

K.Riisager et al.
ISOLDE (1990)
branching ratio
$[BR] = (2.8 \pm 0.5) \times 10^{-6}$

M.J.G.Borge et al.
ISOLDE (1993)
$[BR] = (7.6 \pm 0.6) \times 10^{-6}$

P Descouvemont et al.
potential model (1992)
$[BR] = 2.0 \times 10^{-4}$

Experiment $\leftrightsquigarrow$ Theory

K.Riisager et al.

ISOLDE (1990)

branching ratio

$[BR] = (2.8 \pm 0.5) \times 10^{-6}$

M.J.G.Borge et al.

ISOLDE (1993)

$[BR] = (7.6 \pm 0.6) \times 10^{-6}$

P Descouvemont et al.

potential model (1992)

$[BR] = 2.0 \times 10^{-4}$

M.V.Zhukov et al.

three body model (1993)

$[BR] = (3 - 4) \times 10^{-5}$

Experiment $\leftrightsquigarrow$ Theory

K.Riisager et al.
ISOLDE (1990)
branching ratio
$[BR] = (2.8 \pm 0.5) \times 10^{-6}$

M.J.G.Borge et al.
ISOLDE (1993)
$[BR] = (7.6 \pm 0.6) \times 10^{-6}$

P Descouvemont et al.
potential model (1992)
$[BR] = 2.0 \times 10^{-4}$

M.V.Zhukov et al.
three body model (1993)
$[BR] = (3 - 4) \times 10^{-5}$

D.Baye et al.
Halo-evidence in quenching (1994)
sensitivity to wavefunctions at large distances (15fm)

Experiment ⇝ Theory

K.Riisager et al.
ISOLDE (1990)
branching ratio
$[BR] = (2.8 \pm 0.5) \times 10^{-6}$

M.J.G.Borge et al.
ISOLDE (1993)
$[BR] = (7.6 \pm 0.6) \times 10^{-6}$

P Descouvemont et al.
potential model (1992)
$[BR] = 2.0 \times 10^{-4}$

M.V.Zhukov et al.
three body model (1993)
$[BR] = (3 - 4) \times 10^{-5}$

D.Baye et al.
Halo-evidence in quenching (1994)
sensitivity to wavefunctions at large distances (15fm)

Attila Csótó and Daniel Baye
Microscopic description (1994)
experimental spectrum underestimated by a factor of 1.7

Experiment $\leftrightsquigarrow$ Theory

K.Riisager et al.
ISOLDE (1990)
branching ratio
$[BR] = (2.8 \pm 0.5) \times 10^{-6}$

M.J.G.Borge et al.
ISOLDE (1993)
$[BR] = (7.6 \pm 0.6) \times 10^{-6}$

D.Anthony et al.
TRIUMF (2006)
$[BR] = (1.8 \pm 0.9) \times 10^{-6}$

P Descouvemont et al.
potential model (1992)
$[BR] = 2.0 \times 10^{-4}$

M.V.Zhukov et al.
three body model (1993)
$[BR] = (3 - 4) \times 10^{-5}$

D.Baye et al.
Halo-evidence in quenching (1994)
sensitivity to wavefunctions at large distances (15fm)

Attila Csótó and Daniel Baye
Microscopic description (1994)
experimental spectrum underestimated by a factor of 1.7

Experiment ⇝ Theory

K.Riisager et al.
ISOLDE (1990)
branching ratio
$[BR] = (2.8 \pm 0.5) \times 10^{-6}$

M.J.G.Borge et al.
ISOLDE (1993)
$[BR] = (7.6 \pm 0.6) \times 10^{-6}$

D.Anthony et al.
TRIUMF (2006)
$[BR] = (1.8 \pm 0.9) \times 10^{-6}$

- discrepancies (E,T) $\longleftrightarrow$ (E,T)
- large experimental uncertainties

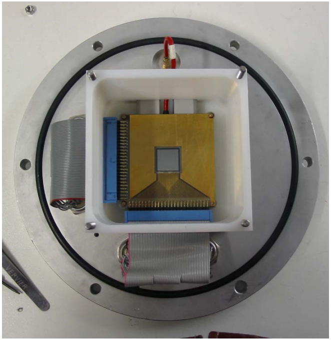
P Descouvemont et al.
potential model (1992)
$[BR] = 2.0 \times 10^{-4}$

M.V.Zhukov et al.
three body model (1993)
$[BR] = (3 - 4) \times 10^{-5}$

D.Baye et al.
Halo-evidence in quenching (1994)
sensitivity to wavefunctions at large distances (15fm)

Attila Csótó and Daniel Baye
Microscopic description (1994)
experimental spectrum underestimated by a factor of 1.7

Goals - Problems - Solution



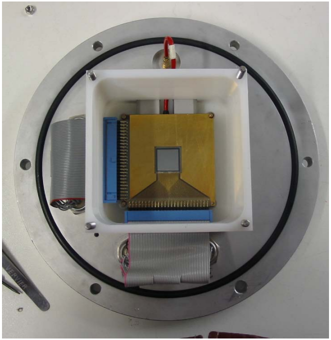
Goals

- Branching Ratio
- shape of deuteron spectrum

Problems

- Normalization (efficiency)
- β "background"

Goals - Problems - Solution



Goals

- Branching Ratio
- shape of deuteron spectrum

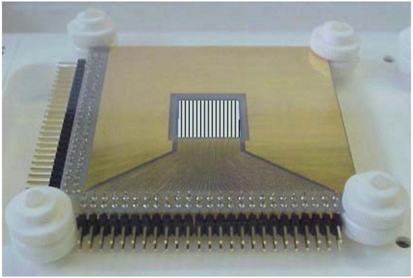
Problems

- Normalization (efficiency)
- β "background"

Solution: direct implantation of RIB in a Double Sided Silicon Strip Detector

$\Longleftrightarrow$ other experiments; implantations on a C-foil
large uncertainty on normalization and efficiency
$\Longrightarrow$ no good precision on [BR]

Implantation in a silicon detector



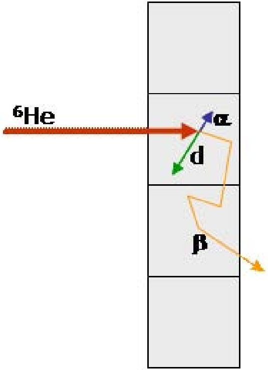
16×16 mm^2, 78 μm thick
48+48 strips, 300 μm wide
2304 pixels

D. Smirnov, R. Raabe et al.
Nuclear Instruments & Methods in Physics Research A 547, 2005

Implantation in a DSSSD:

- Uniform profile
- Middle plane of the detector

Implantation in a silicon detector



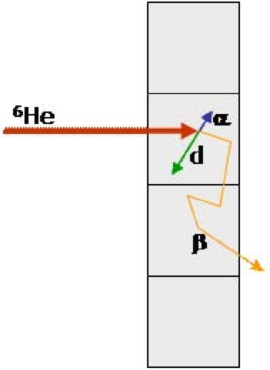
Implantation in a DSSSD:

- Uniform profile
- Middle plane of the detector

Advantages

- Full energy of particles is measured
  $\Longrightarrow$ calorimetric method
- High efficiency !
- Very precise normalisation !
- Suppression of signals from β particles
  $\Rightarrow$ low detection threshold !
- "History" of each decay

Implantation in a silicon detector



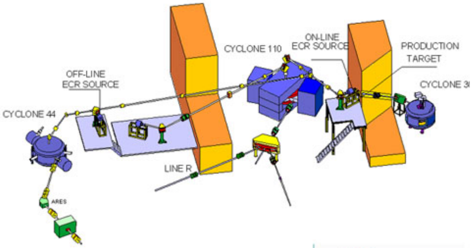
Implantation in a DSSSD:

- Uniform profile
- Middle plane of the detector

Advantages

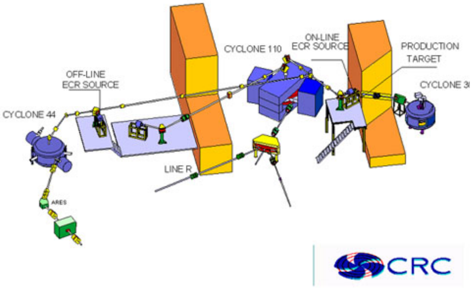
- Full energy of particles is measured
  $\Longrightarrow$ calorimetric method
- High efficiency !
- Very precise normalisation !
- Suppression of signals from β particles
  $\Rightarrow$ low detection threshold !
- "History" of each decay

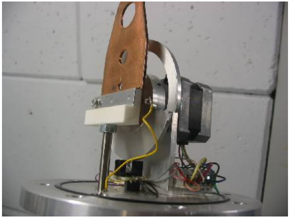
CRC facility - setup



- $E(^{6}He) = 8MeV$
- spurious low-energy beam induced signals

CRC facility - setup

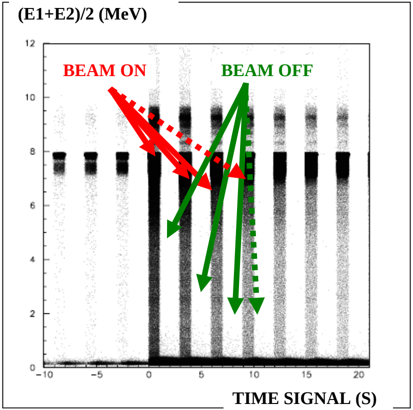




- E(^{6}He)=8MeV
- spurious low-energy beam induced signals
  $\Longrightarrow$ shutter wheel ;
  beam on/off intervals 1s/2s

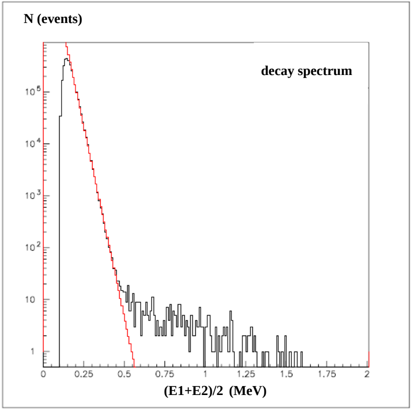
Beam ON/OFF time structure

Where do we find the interesting $\alpha + d$ events?
$\Longrightarrow$ Defining the beam_on/off periods



Results

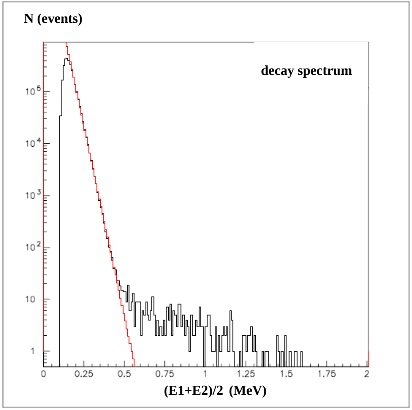
α+d-spectrum



- Total time = 66h
- $N_{impl} \simeq 203 \times 10^6$
  $N_{\alpha+d}$=315 (above 525keV)
- Total deadtime :
  - beam_on=56%
  - beam_off=4%
- only α+d events during beam_off
  $\Longrightarrow$ correction factor, κ=0.44

Results

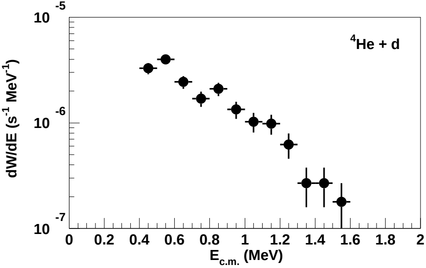
α+d-spectrum



- Total time = 66h
- $N_{impl} \simeq 203 \times 10^6$
  $N_{\alpha+d}$=315 (above 525keV)
- Total deadtime :
  - beam_on=56%
  - beam_off=4%
- only α+d events during beam_off
  $\Longrightarrow$ correction factor, κ=0.44

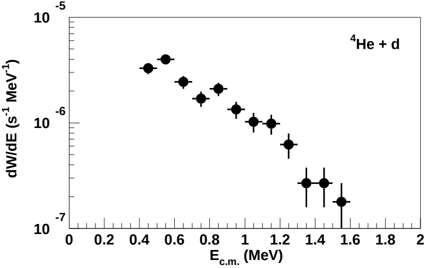
$$BR = \frac{N'_{\alpha+d}}{N'_{impl}} = (1.62 \pm 0.11) \times 10^{-6}$$

Results - Comparison



$$BR = (1.62 \pm 0.11) \times 10^{-6}$$

Results - Comparison

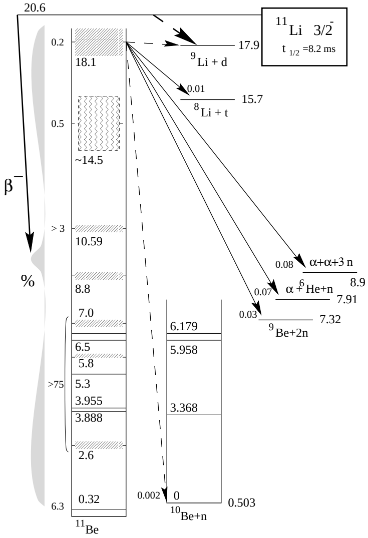


$BR = (1.62 \pm 0.11) \times 10^{-6}$

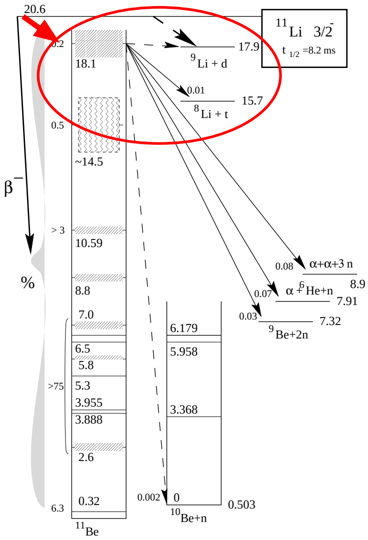
Comparison

- previous measurements:
  $BR = (1.7 \pm 0.4) \times 10^{-6}$ and
  $BR = (2.03 \pm 0.35) \times 10^{-6}$
- independent theoretical development
  - E.M.Tursunov, D.Baye, P.Descouvemont
    three-body model (2006)
    $BR = 1.86 \times 10^{-6}$
- agreement with TRIUMF measurement
  $BR = (1.8 \pm 0.9) \times 10^{-6}$

^{11}Li at TRIUMF

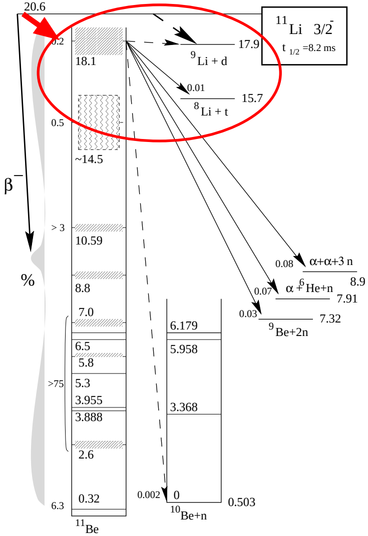


^{11}Li at TRIUMF

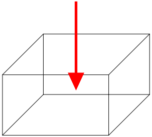


- Decay into the continuum: ^{9}Li+d
  $B.R. \approx 10^{-4}$ (but ^{8}Li+t also present)
  [I. Mukha et al., PLB 367 (1996) 65]

^{11}Li at TRIUMF



- Decay into the continuum: ^{9}Li+d
  $B.R. \approx 10^{-4}$ (but ^{8}Li+t also present)
  [I. Mukha et al., PLB 367 (1996) 65]
- Method: identification through decay of the daughter nuclei

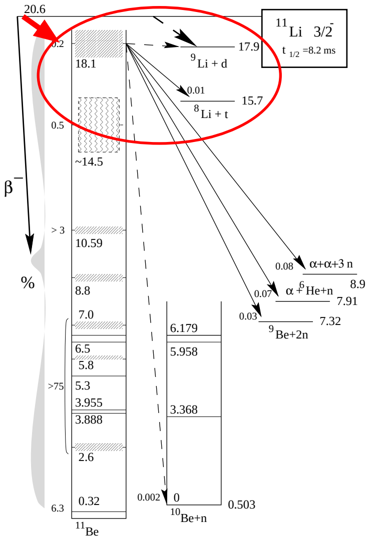


implantation

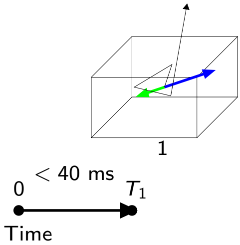
0

Time

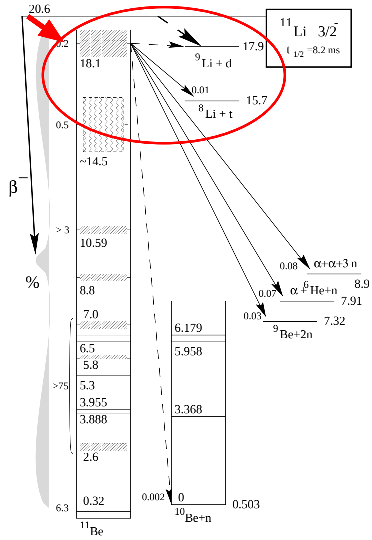
^{11}Li at TRIUMF



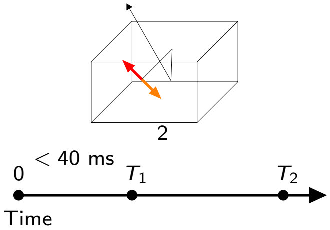
- Decay into the continuum: ^{9}Li+d
  $B.R. \approx 10^{-4}$ (but ^{8}Li+t also present)
  [I. Mukha et al., PLB 367 (1996) 65]
- Method: identification through decay of the daughter nuclei



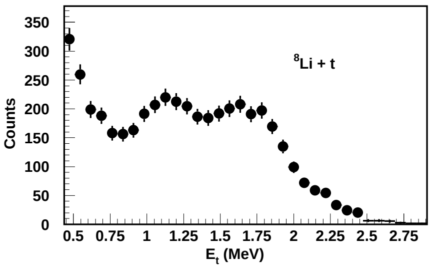
^{11}Li at TRIUMF

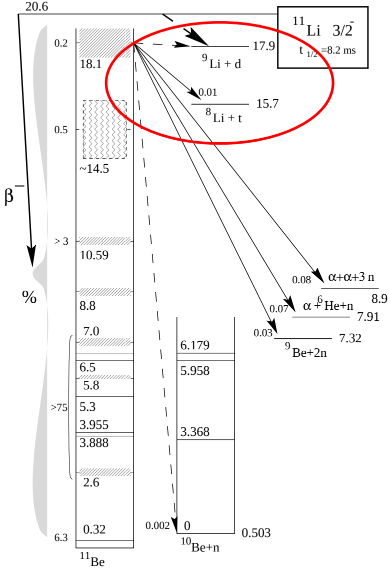


- Decay into the continuum: ^{9}Li+d
  $B.R. \approx 10^{-4}$ (but ^{8}Li+t also present)
  [I. Mukha et al., PLB 367 (1996) 65]
- Method: identification through decay of the daughter nuclei

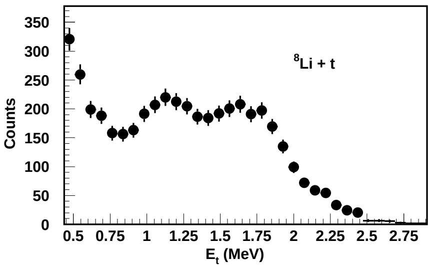


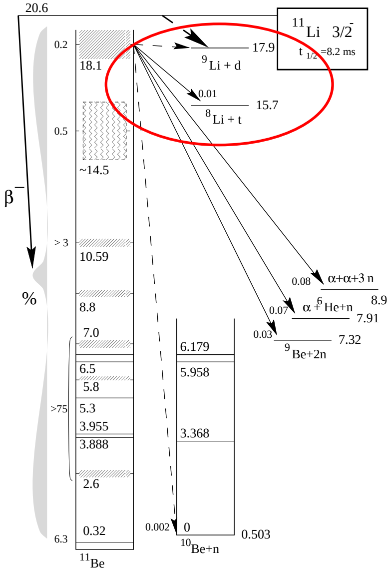
Results: $^{11}Li \xrightarrow{\beta} {}^{8}Li+t,\ {}^{9}Li+d$





Results: $^{11}\text{Li} \xrightarrow{\beta} {}^{8}\text{Li+t}, {}^{9}\text{Li+d}$



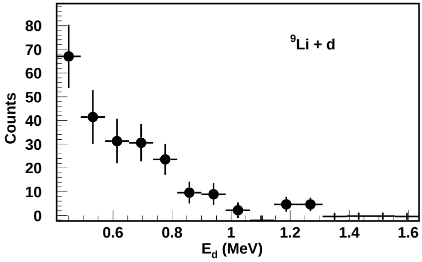


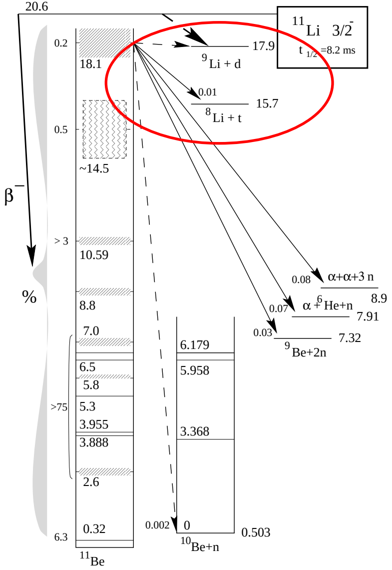
Branching ratio ^{8}Li+t:

$$1.7(2) \times 10^{-4}$$

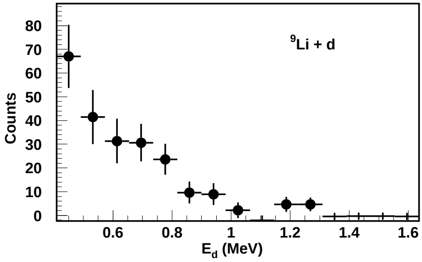
$(0.4 \text{ MeV} < E_{cm} < 3.0 \text{ MeV})$

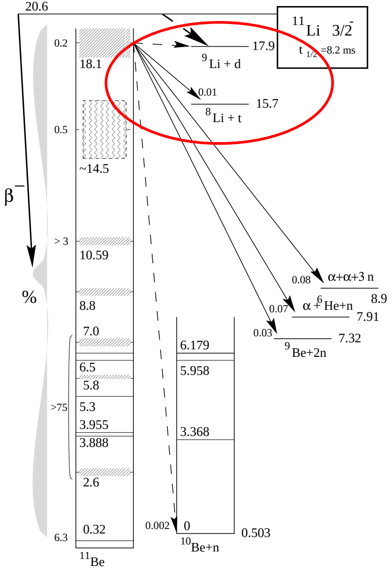
Results: $^{11}\mathrm{Li} \xrightarrow{\beta} {}^{8}\mathrm{Li}+t,\ {}^{9}\mathrm{Li}+d$





Results: $^{11}\text{Li} \xrightarrow{\beta} {}^{8}\text{Li+t},\ {}^{9}\text{Li+d}$





Branching ratio ^{9}Li+d:

$$7.3(7) \times 10^{-5}$$

$(0.4\ \text{MeV} < E_{cm} < 3.0\ \text{MeV})$

Overview

Overview

- ^{6}He
  Branching Ratio with precision of 7% in good agreement with theoretical predictions

Overview

- ^{6}He
  Branching Ratio with precision of 7% in good agreement with theoretical predictions
- ^{11}Li
  For the 1st time, the BR of the $^{9}Li+d$ and the $^{8}Li+t$ decay branch could be measured separately and with good precision!

Overview

- ^{6}He
  Branching Ratio with precision of 7% in good agreement with theoretical predictions
- ^{11}Li
  For the 1st time, the BR of the ^{9}Li+d and the ^{8}Li+t decay branch could be measured separately and with good precision!
- ^{12}C through β-decay of ^{12}N and ^{12}B (KVI)
  Very low threshold $\Rightarrow$ Hoyle state observed 0.3 MeV above the 3α-threshold
  Branching ratios revised with a factor 10 more precise

Overview

- ^{6}He
  Branching Ratio with precision of 7% in good agreement with theoretical predictions
- ^{11}Li
  For the 1st time, the BR of the ^{9}Li+d and the ^{8}Li+t decay branch could be measured separately and with good precision!
- ^{12}C through β-decay of ^{12}N and ^{12}B (KVI)
  Very low threshold ⇒ Hoyle state observed 0.3 MeV above the 3α-threshold
  Branching ratios revised with a factor 10 more precise
- ^{8}B
  Proposal has just been accepted for the full beamtime!
  Comparison of laboratory neutrino spectrum with solar-neutrino detectors spectra
  derived from the shape of the 2^{+} continuum in ^{8}Be

β-decay study of ^{6}He & ^{11}Li

Jeroen Büscher Riccardo Raabe
Piet Van Duppen Mark Huyse

IKS - Nuclear Spectroscopy

IAP-day, Leuven - January 23, 2007